Occurrence of Kelvin-Helmholtz Billows in Sea Breezes

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Kelvin-Helmholtz Billows

- Shear instability behind sea-breeze front.
- Wavelength of 1 or 2km.
- About 20min between waves for fixed observer.

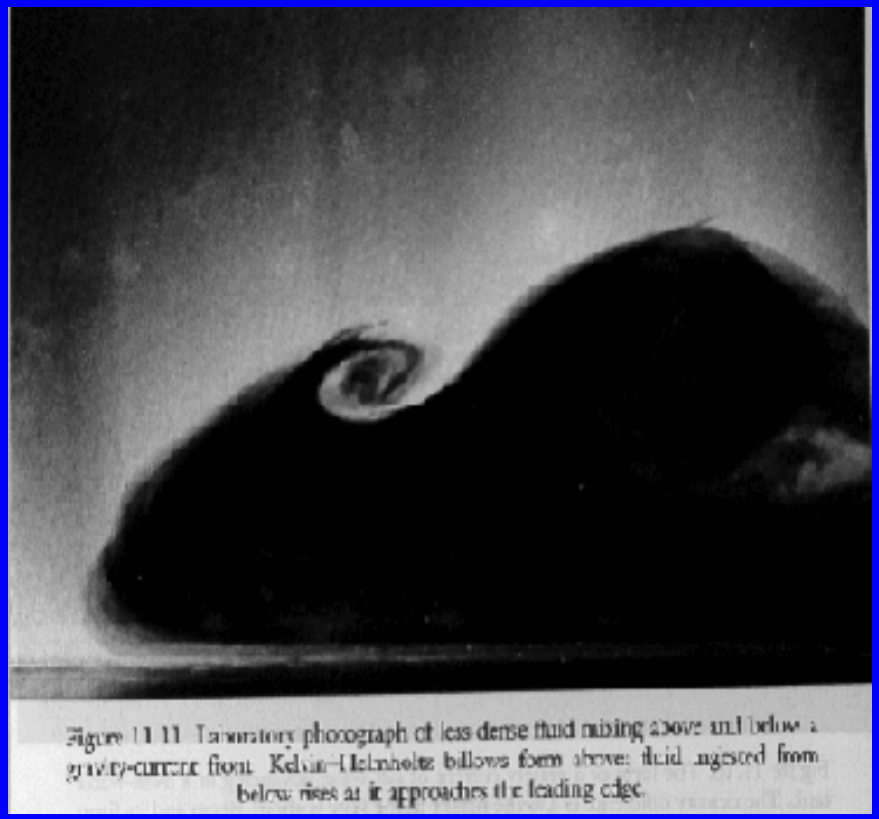
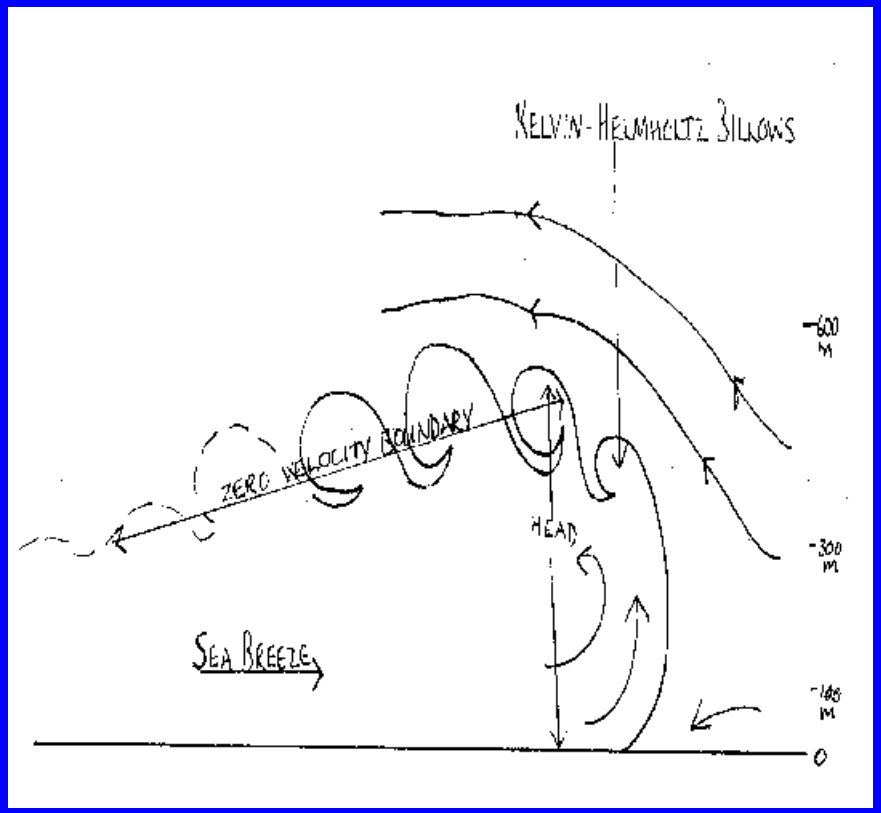


Figure 11.11 Laboratory photograph of less dense fluid mixing above and below a gravity-current front. Kelvin–Helmholtz billows form above; fluid ingested from below rises as it approaches the leading edge.



(Simpson 1994)

Evidence of KHB in the Atmosphere

- Tethered balloon measurements (Lapworth 2000)

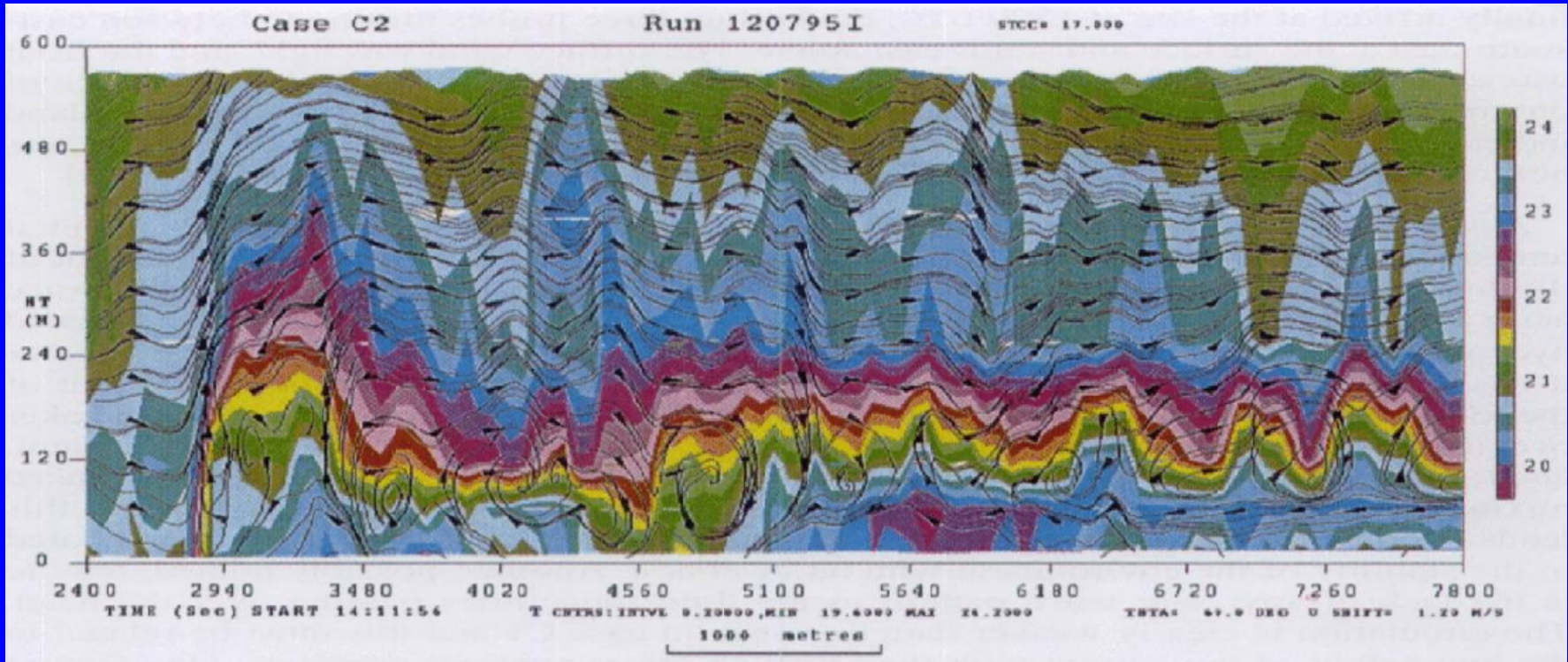


Figure 5. Contours of potential temperature (°C) and streamlines of flow measured for case C2 (see text) between 1452 and 1622 UTC. The section direction is towards 60° magnetic at the right-hand side and streamlines are relative to a frontal speed of 1.2 m s^{-1}. Other details are as in the legend to Fig. 3.

- Also with aircraft, with radar, in surface obs, in lab and numerically modelled (for ?x~ 100m).
- May produce peak in power spectrum (Wood et al 1999)

Importance of KH Billows

- Initiation of convection (Rao and Fulberg 2000)
  - typical w~0.5m/s
  - ~ 15% of convection associated with sea breezes is postfrontal
- Inland propagation of front (Sha et al 1991)
- Transport of pollutants (Buckley and Kurzeja 1997)

- But…

- Sometimes present, sometimes not!

- For given synoptic conditions, KHB are consistent features with consistent properties (Alpert and Rabinovich-Hadar 2003)

An Indication from Lab Experiments

- Less prominent billows for gravity currents propagating into a head wind.
- Not tested for real sea breezes.
- No other known indicators of occurence.

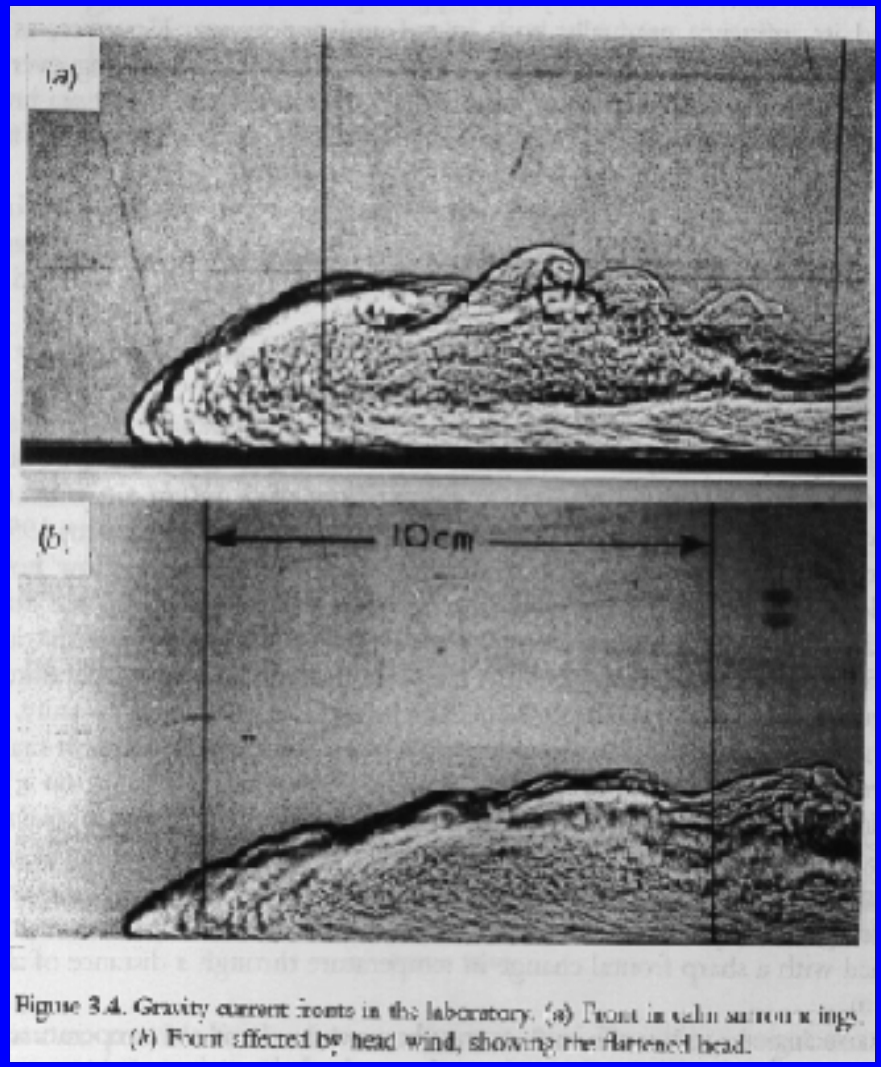


Figure 3.4. Gravity current fronts in the laboratory. (a) Front in calm surroundings. (b) Front affected by head wind, showing the flattened head.

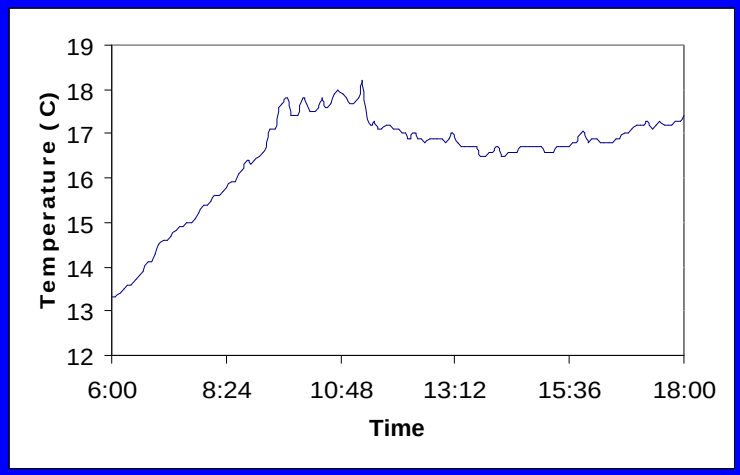
(Simpson and Britter 1980)

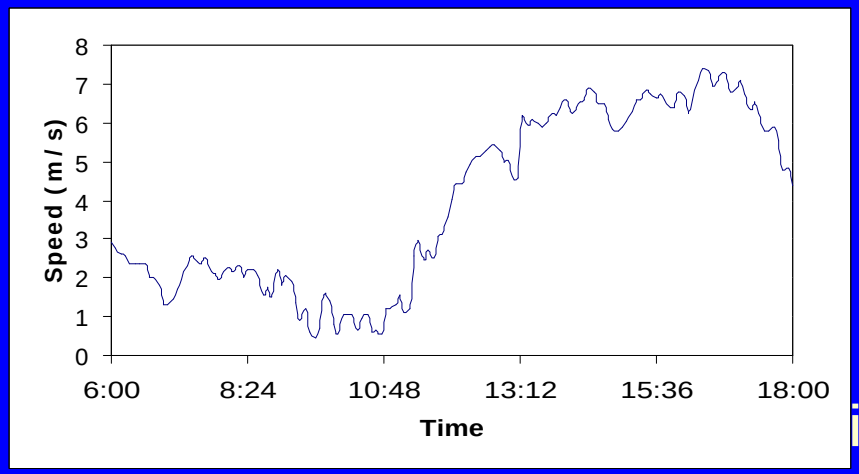
Sea Breeze Database

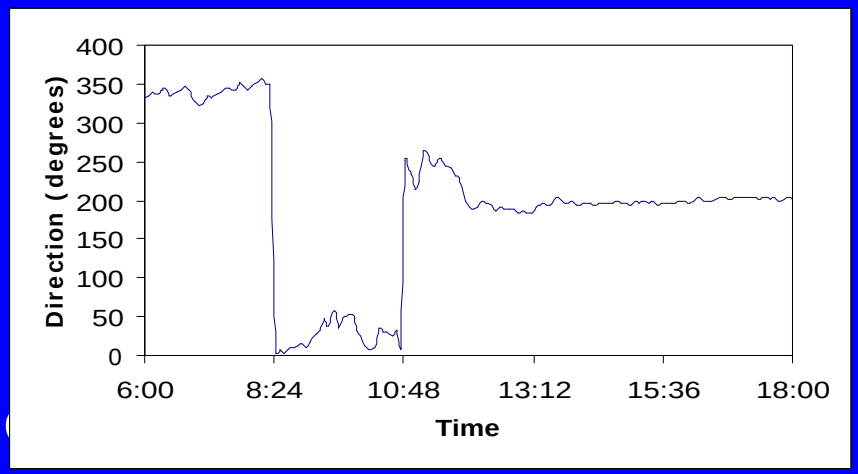
- Data from Chimet, at entrance to Chichester harbour.
- Measurements every 1s reported as 5min averages.
- Automated detection criteria based on:
  - an onshore wind direction;
  - required shifts in temperature, wind speed, direction;
  - a peak gustiness.

Detection of Sea Breeze Fronts

- Example for 24/06/03, at 1100.

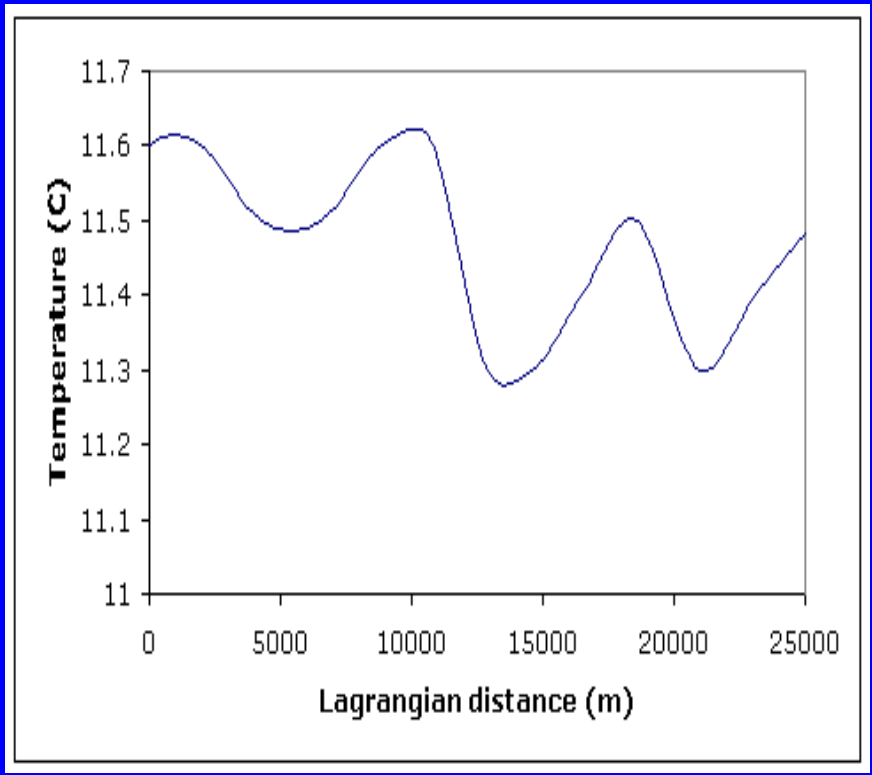


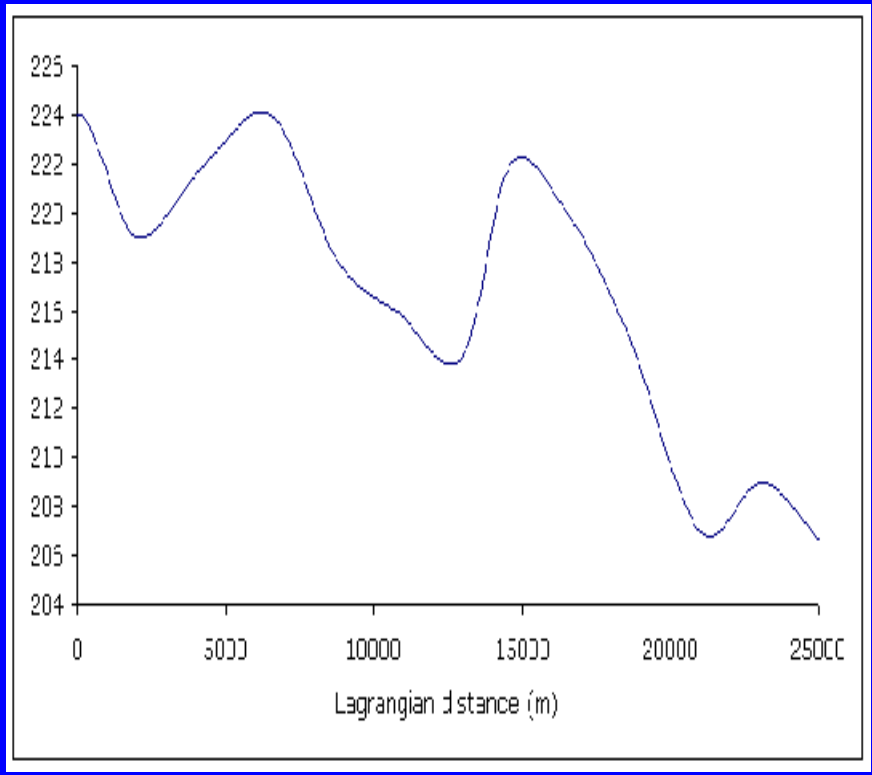




Identification of KHB

- Look for oscillations in surface pressure, temperature, wind speed and direction.
- Assign 2 if definitely present, 0 if definitely not and 1 in debatable cases.

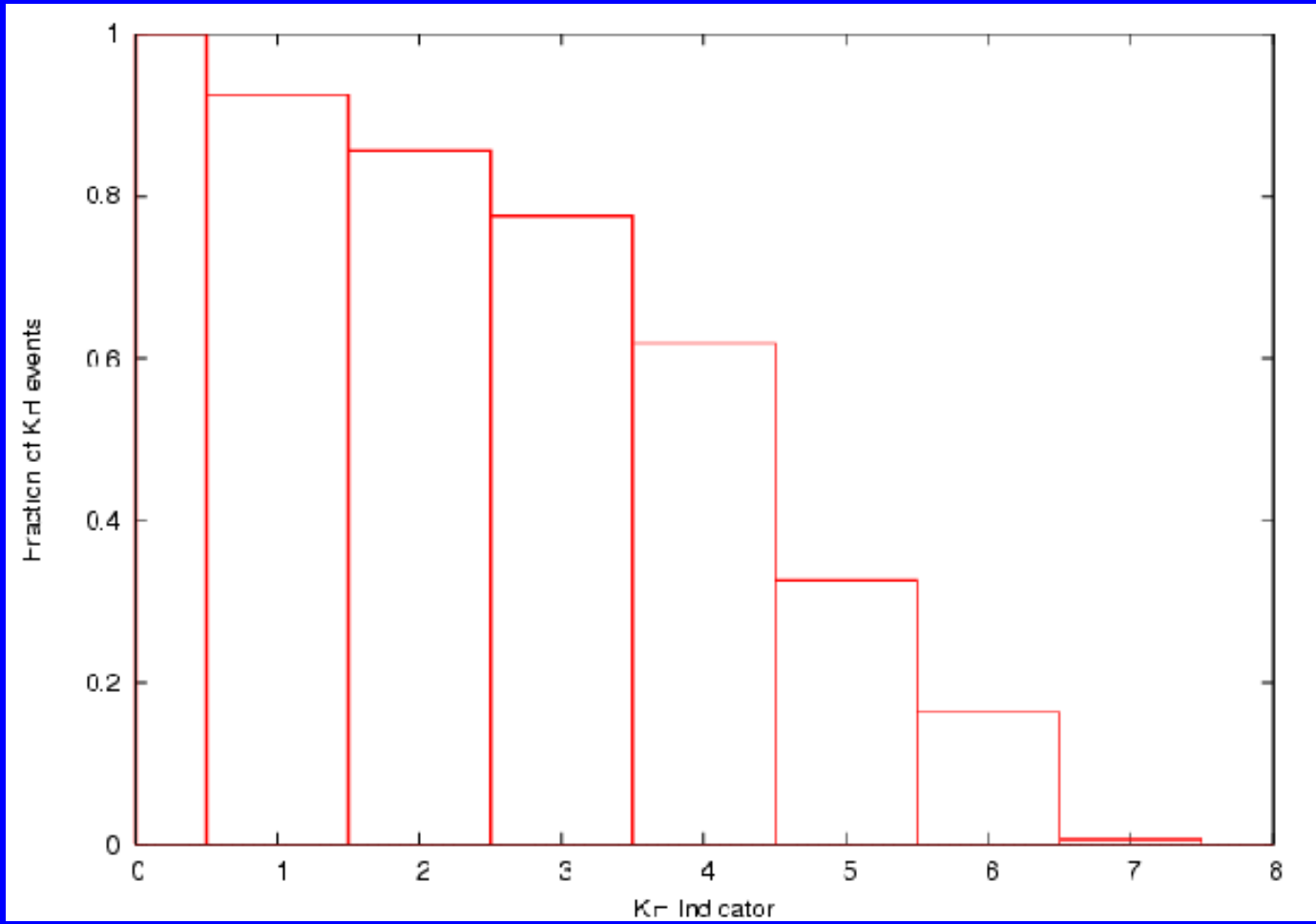




Example for 12/05/03.

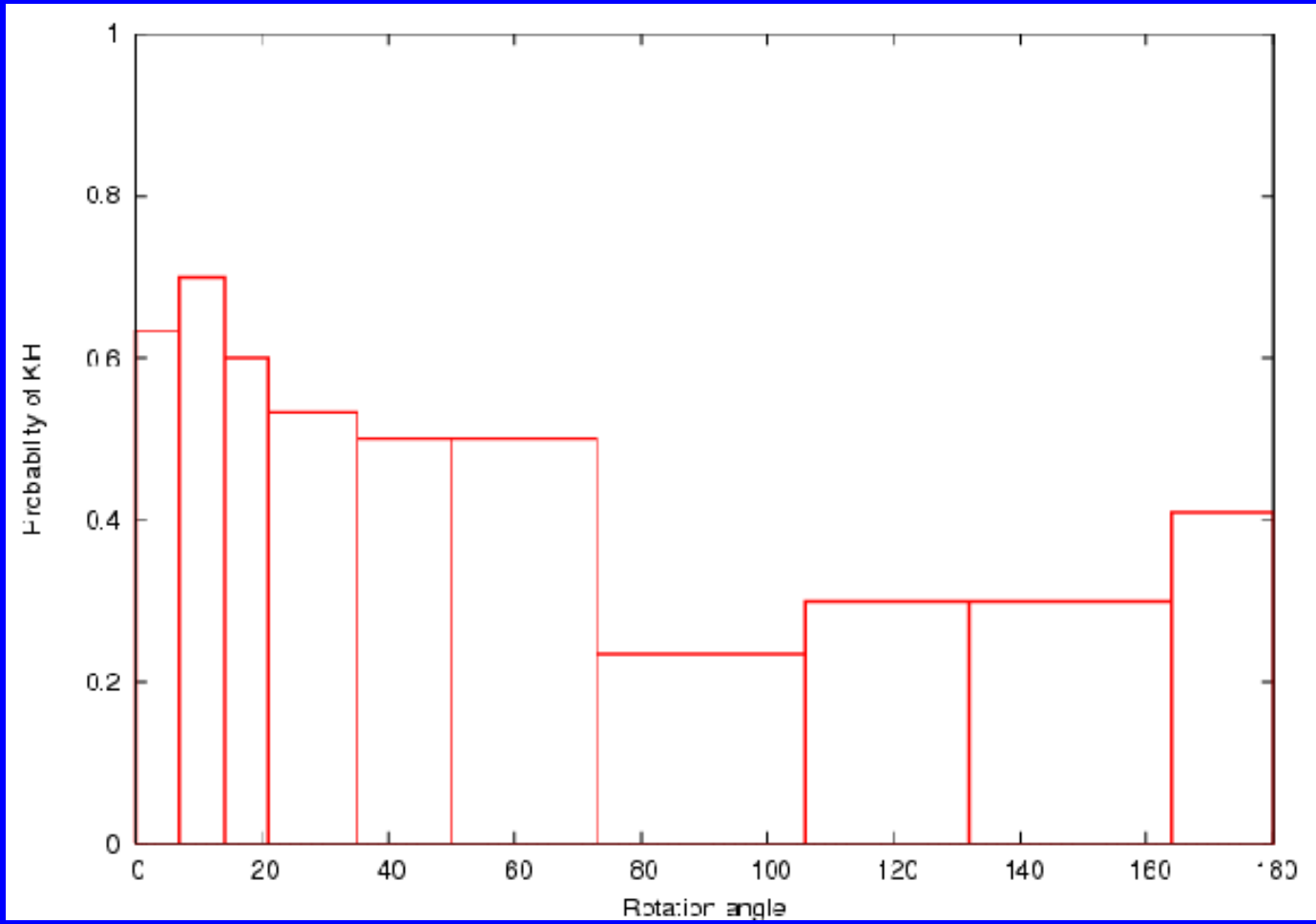
The KHB Indicator

- Proportion of events exceeding a score of...



Effect of Shift in Wind Direction

- Angular shift between winds one hour before and after the front...



Conclusions

- KHB are more likely in sea breezes with…
  - Onshore winds beforehand (small rotations).
  - Increasing wind speed beforehand, for moderate winds of up to 6 or 7 m/s, with reduced chances for stronger winds.
  - Frontal formation earlier in the day.
  - Relatively rapid inland propagation of front.
  - Possible influence of coastline shape (apparent variations with direction of inland propagation).
- No discernible effects of land-sea temperature difference.